CSE 3302
Programming Languages

Syntax (cont.)

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What is Parsing?

- **Given a grammar and a token string:**
  – determine if the grammar can generate the token string?
  – i.e., is the string a legal program in the language?
- **In other words, to construct a parse tree for the token string.**

What's significant about parse tree?

A parse tree gives a unique syntactic structure

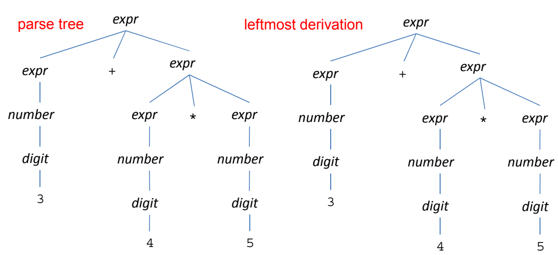
- Leftmost, rightmost derivation
- There is only one leftmost derivation for a parse tree, and symmetrically only one rightmost derivation for a parse tree.

Example

$expr \rightarrow expr + expr \mid expr * expr \mid (\; expr \;) \mid number$

$number \rightarrow number \; digit \mid digit$

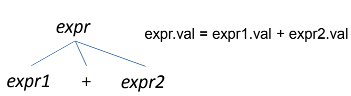
$digit \rightarrow 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9$



What's significant about parse tree?

A parse tree has a unique meaning, thus provides basis for semantic analysis.

(Syntax-directed semantics: semantics are attached to syntactic structure.)



Relationship among language, grammar, parser

- Chomsky Hierarchy
  http://en.wikipedia.org/wiki/Chomsky_hierarchy
- A language can be described by multiple grammars, while a grammar defines one language.
- A grammar can be parsed by multiple parsers, while a parser accepts one grammar, thus one language.
- Should design a language that allows simple grammar and efficient parser
- For a language, we should construct a grammar that allows fast parsing
- Given a grammar, we should build an efficient parser

Ambiguity

- **Ambiguous grammar:** There can be multiple parse trees for the same sentence (program)
  - In other words, multiple leftmost derivations.
- **Why is it bad?**
  - Multiple meanings

Ambiguity

- **Was this ambiguous?**

number → *number digit* | *digit*
digit → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

- **How about this?**

expr → *expr* - *expr* | *number*

Deal with Ambiguity

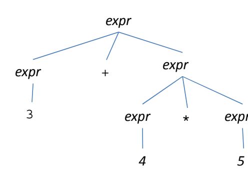
- **Unambiguous Grammar**
  - Rewrite the grammar to avoid ambiguity.

Example of Ambiguity: Precedence

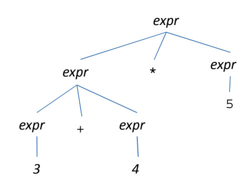
expr → *expr* + *expr* | *expr* * *expr* | (*expr*) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Two different parse tress for expression 3+4*5

parse tree 1



parse tree 2



Eliminating Ambiguity for Precedence

- Establish "precedence cascade": using different structured names for different constructs, adding grammar rules.
  - Higher precedence : lower in cascade

expr → *expr* + *expr* | *expr* * *expr* | (*expr*) | *number*

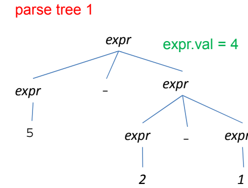
expr → *expr* + *expr* | *term*
term → *term* * *term* | (*expr*) | *number*

Example of Ambiguity: Associativity

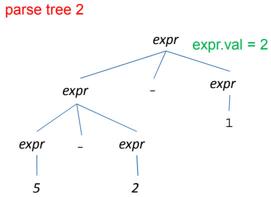
expr → *expr* - *expr* | (*expr*) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Two different parse tress for expression 5-2-1

parse tree 1



parse tree 2



- is right-associative, which is against common practice in integer arithmetic

- is left-associative, which is what we usually assume

Associativity

- Left-Associative: + - * /
- Right-Associative: =
  What is meant by a=b=c=1?

Eliminating Ambiguity for Associativity

- **left-associativity: left-recursion**

expr → *expr* - *expr* | (*expr*) | *number*

⇒

expr → *expr* - *term* | *term*
term → (*expr*) | *number*

- **right-associativity: right-recursion**

expr → *expr* = *expr* | a | b | c

⇒ *expr* → *term* = *expr* | *term*
term → a | b | c

Putting Together

expr → *expr* - *expr* | *expr* / *expr* | (*expr*) | *number*
number → *number digit* | *digit*
digit → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

We want to make - left-associative and / has precedence over -

⇒

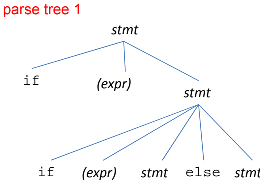
expr → *expr* - *term* | *term*
term → *term* / *factor* | factor
factor → (*expr*) | *number*
number → *number digit* | *digit*
digit → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Example of Ambiguity: Dangling-Else

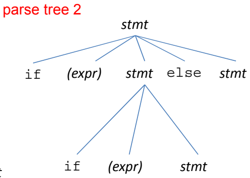
stmt → `if` (*expr*) *stmt*
| `if` (*expr*) *stmt* `else` *stmt*
| *other-stmt*

Two different parse trees for "**if(** ***expr*** **) if(** ***expr*** **)** ***stmt*** **else** ***stmt***"

parse tree 1



parse tree 2



Eliminating Dangling-Else

stmt → *matched_stmt*
| *unmatched_stmt*
matched_stmt → `if` (*expr*) *matched_stmt* `else` *matched_stmt*
| *other-stmt*
unmatched_stmt → `if` (*expr*) *stmt*
| `if` (*expr*) *matched_stmt* `else` *unmatched_stmt*

EBNF

- Repetition { }

number → *digit* | *number digit* ⇒ *number* → { *digit* }

expr → *expr* - *term* | *term* ⇒ *expr* → *term* {– *term*}

- Option [ ]

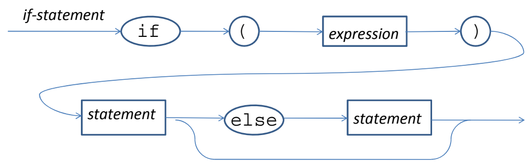
signed-number → sign number
| *number* ⇒ *signed-number* → [sign] *number*

if-stmt → `if` (*expr*) *stmt*
| `if` (*expr*) *stmt* `else` *stmt* ⇒ *if-stmt* → `if` (*expr*) *stmt* [`else` *stmt*]

Syntax Diagrams

- Written from EBNF, not BNF
- If-statement

  (more examples on page 101)



Parsing Techniques

- Intuitive analysis and conclusion
- No formal theorems and rigorous proofs
- More details: compilers, automata theory

Parsing

- **Parsing:**
  - Determine if a grammar can generate a given token string.
  - That is, to construct a parse tree for the token string.
- **Two ways of constructing the parse tree**
  - Top-down (from root towards leaves)
    - Can be constructed more easily by hand
  - Bottom-up (from leaves towards root)
    - Can handle a larger class of grammars
    - Parser generators tend to use bottom-up methods

Top-Down Parser

- Recursive-descent parser:
  - A special kind of top-down parser: single left-to-right scan, with one lookahead symbol.
  - Backtracking (trial-and-error) may happen
- Predictive parser:
  - The lookahead symbol determines which production to apply, without backtracking

Recursive-Descent Parser

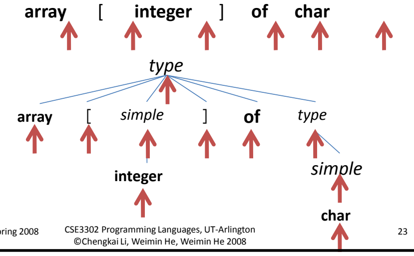
- Types in Pascal

type → ***simple*** | **array** [*simple*] **of** *type*

simple → **char** | **integer**

Input: **array** [**integer**] **of** **char**

Parse tree



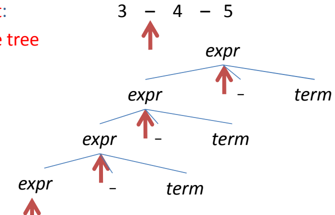
Challenge 1: Top-Down Parser Cannot Handle Left-Recursion

expr → *expr* - *term* | *term*

term → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Input: 3 – 4 – 5

Parse tree



Eliminating Left-Recursion

expr → *expr* - *term* | *term*
term → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

⇒

expr → *term expr'*   *expr'* → – *term expr'* | ε
term → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

⇒ (*EBNF*)

expr → *term* { - *term* }
term → 0 | 1 | … | 9

⇒

```
void expr(void)
{ term();
  while (token == '-')
  { match('-');
    term();
  }
}
```

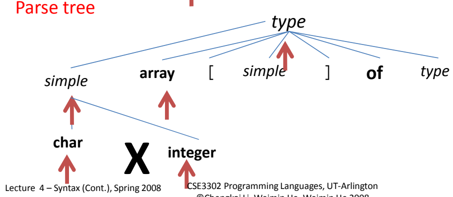

Challenge 2: Backtracking is Inefficient

- **Backtracking: trial-and-error**

type → *simple* | **array** [*simple*] **of** *type*   (Types in Pascal)
simple → **char** | **integer**

Input: **array** [**integer**] **of** **char**

Parse tree



Challenge 2: Backtracking is Inefficient

subscription → *term* | *term* .. *term*
term → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

- We cannot avoid backtracking if the grammar has multiple productions to apply, given a lookahead symbol.
- Solution:
  - Change the grammar so that there is only one applicable production that is unambiguously determined by lookahead symbol.

Avoiding Backtracking by Left Factoring

$A \rightarrow \alpha\, \beta 1 \mid \alpha\, \beta 2$

⇒

$A \rightarrow \alpha\, A'$
$A' \rightarrow \beta 1 \mid \beta 2$

expr → *term* | *term* .. *term*
term → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

⇒

expr → *term rest*
rest → .. *term* | ε
term → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Left Factoring Using EBNF

expr → *term* @ expr | *term*

⇒

expr → *term* [@ expr]

if-statement → if (expr) *statement*
| if (expr) statement else statement

⇒

if-statement → if (expr) *statement* [else statement]